

Science Enables Exploration & Exploration Enables Science. Exploring Lunar Polar Volatile Deposits



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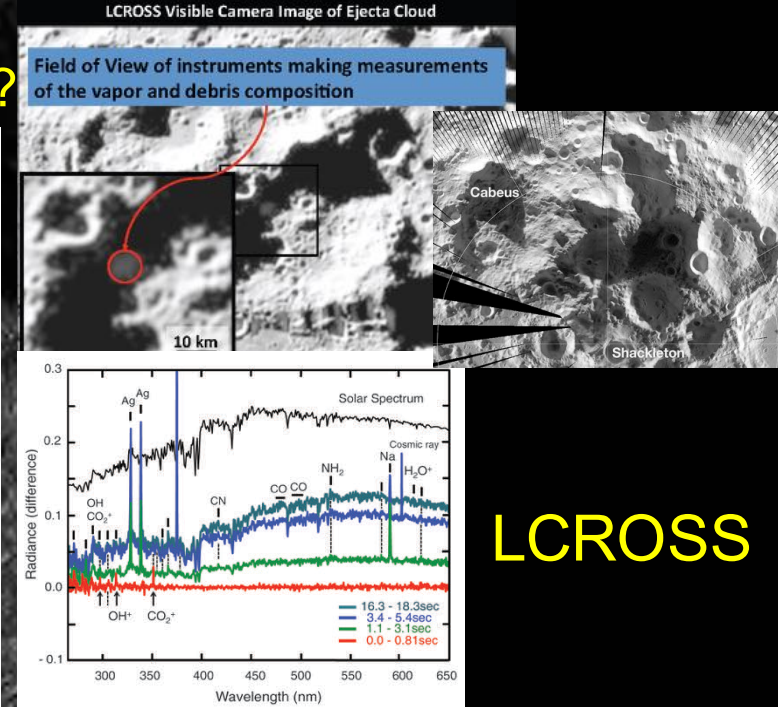
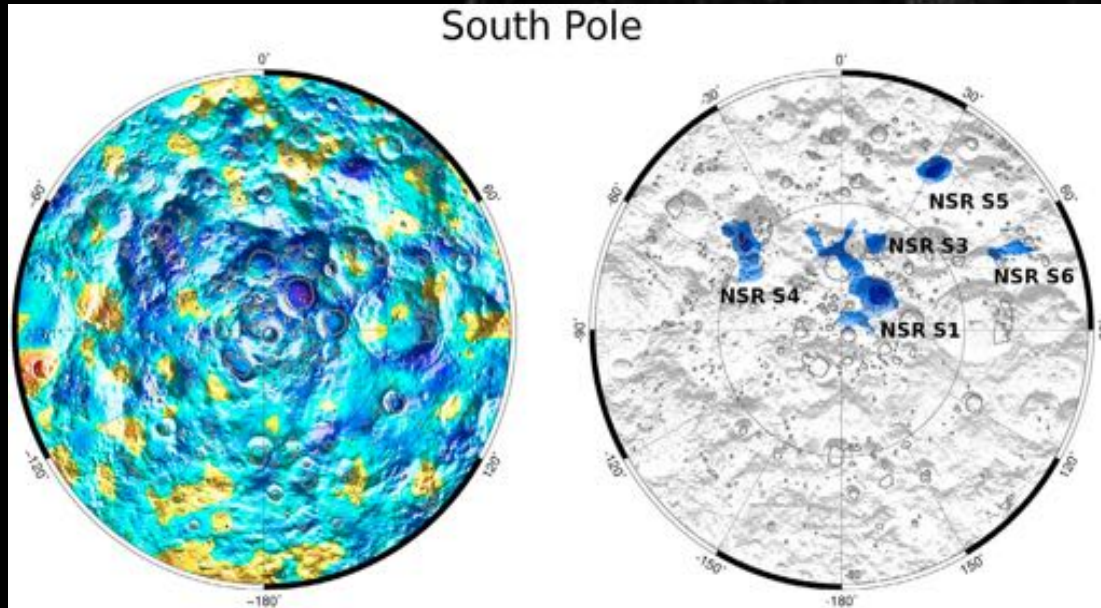
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Ice Permafrost Around PSRs

Neutron Suppression Regions (NSRs) are found in both Permanently Shadowed Regions (PSRs) and illuminated areas, and they are not coincident with PSRs.

In situ exploration and possibly sample return?



LCROSS

Mitrofanov et al. (2012) *JGR*. **117** E00H27, doi:10.1029/2011JE003956.

Colaprete et al. (2010) *Science* **330**, 463-468.
Colaprete et al. (2012) *Space Sci. Rev.* **167**, 3-22

Science & Exploration Synergies

- Capable missions to the surface at the polar regions of the Moon can return important science and exploration data.
- **Lunar Polar Volatiles Explorer** concept was explored during the last decadal survey.
- Nature of polar volatiles was highlighted as an important science topic that should be addressed by future missions.
- 6 landed missions to the South Pole are scheduled between now and 2025.
- Only one of these is from the United States – **Resource Prospector**.
- A partnership between SMD-PSD and HEOMD-AES could build on the **Resource Prospector** mission and the **Lunar Polar Volatiles Explorer** concept to create real synergies between science and exploration

Polar Volatile Deposit Environment

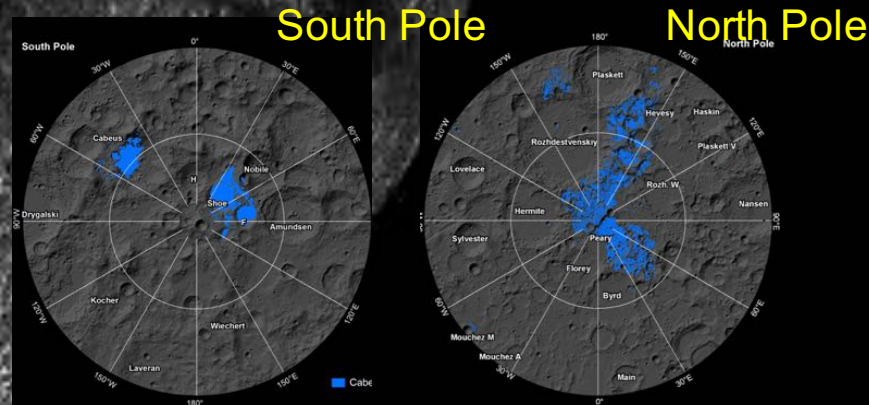
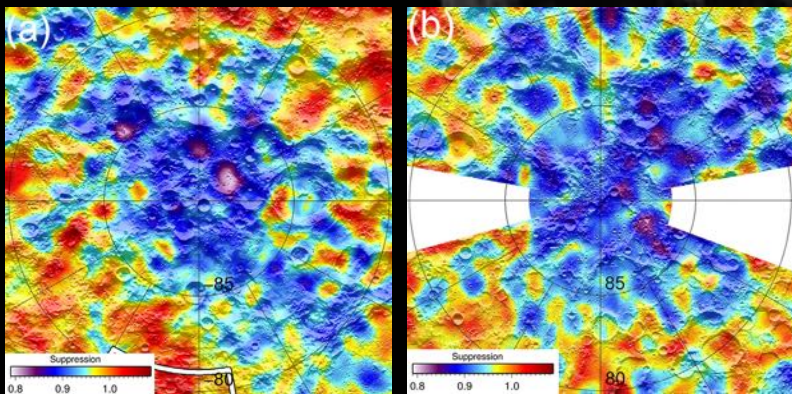
The richest deposits are found inside certain PSRs:

- **South Pole**: Cabeus, Haworth, Shackleton, Nobile;
- **North Pole**: just East of Whipple, Rhozhdestvenskiy U vicinity, western Rhozhdestvenskiy W, portions within and just East and West of Peary; potentially western Hermite.

South Pole

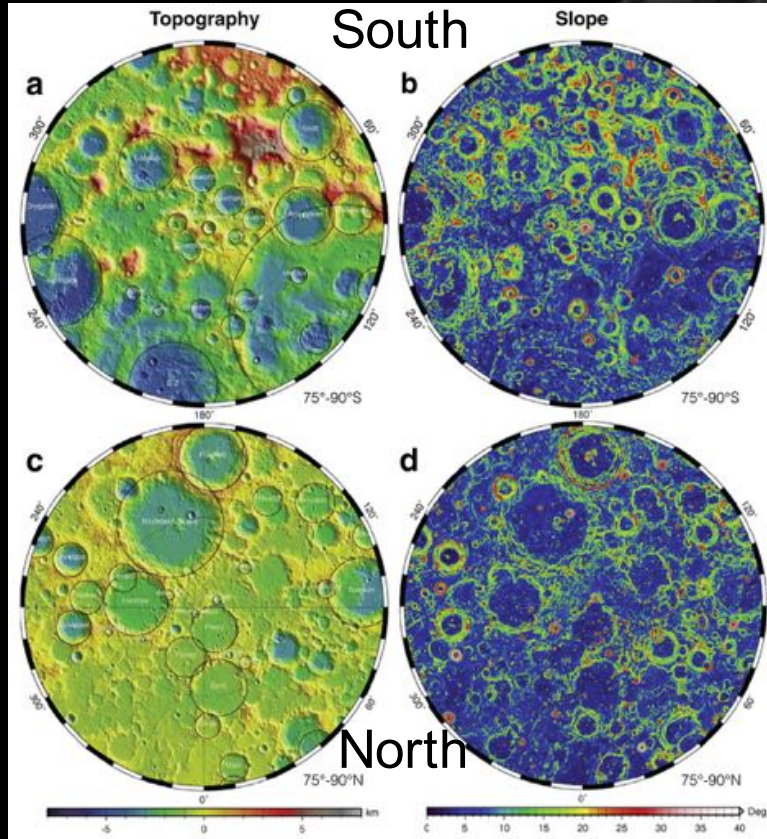
North Pole

http://www.lpi.usra.edu/leag/reports/vsat_report_123114x.pdf



Neutron Suppression Maps: LRO-LEND

Polar Volatile Deposit Environment

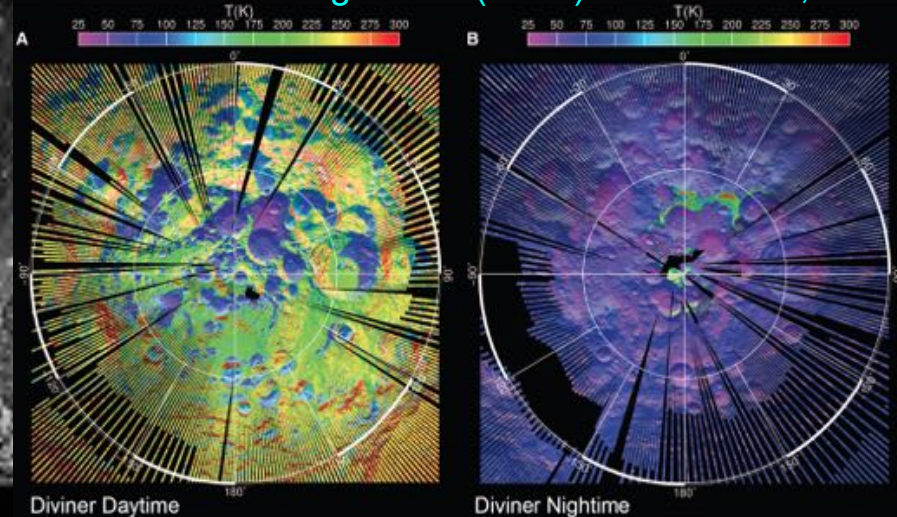


These are some of the coldest places in the Solar System.

Many PSRs have steep slopes.

Requires capable rovers and/or novel exploration strategies to truly explore these deposits.

Paige et al. (2010) *Science* 330, 479-482

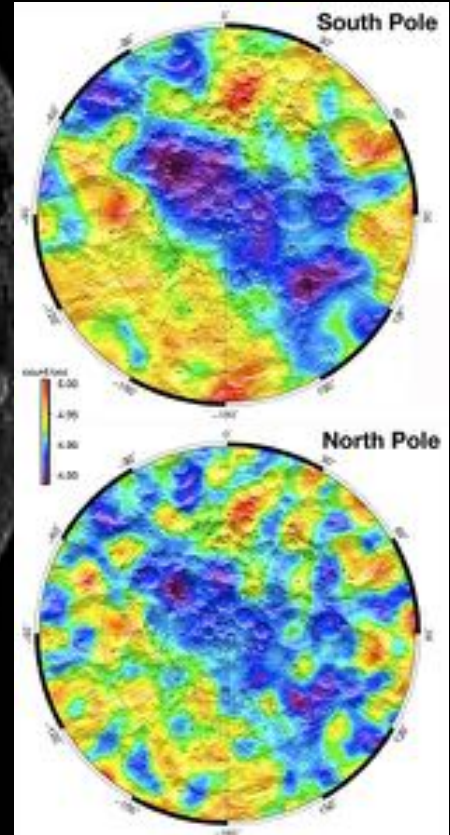


Smith D.E. et al. (2017) *Icarus* **283**, 70-91

Why Should We Explore Polar Volatile Deposits?

Science.

- Understand the origin of such volatiles (endogenous vs. exogenous);
- Potentially understand the lunar volatile cycle;
- Investigate the delivery of volatiles to the inner Solar System;
- Explore if the building blocks for life are present in the deposits.

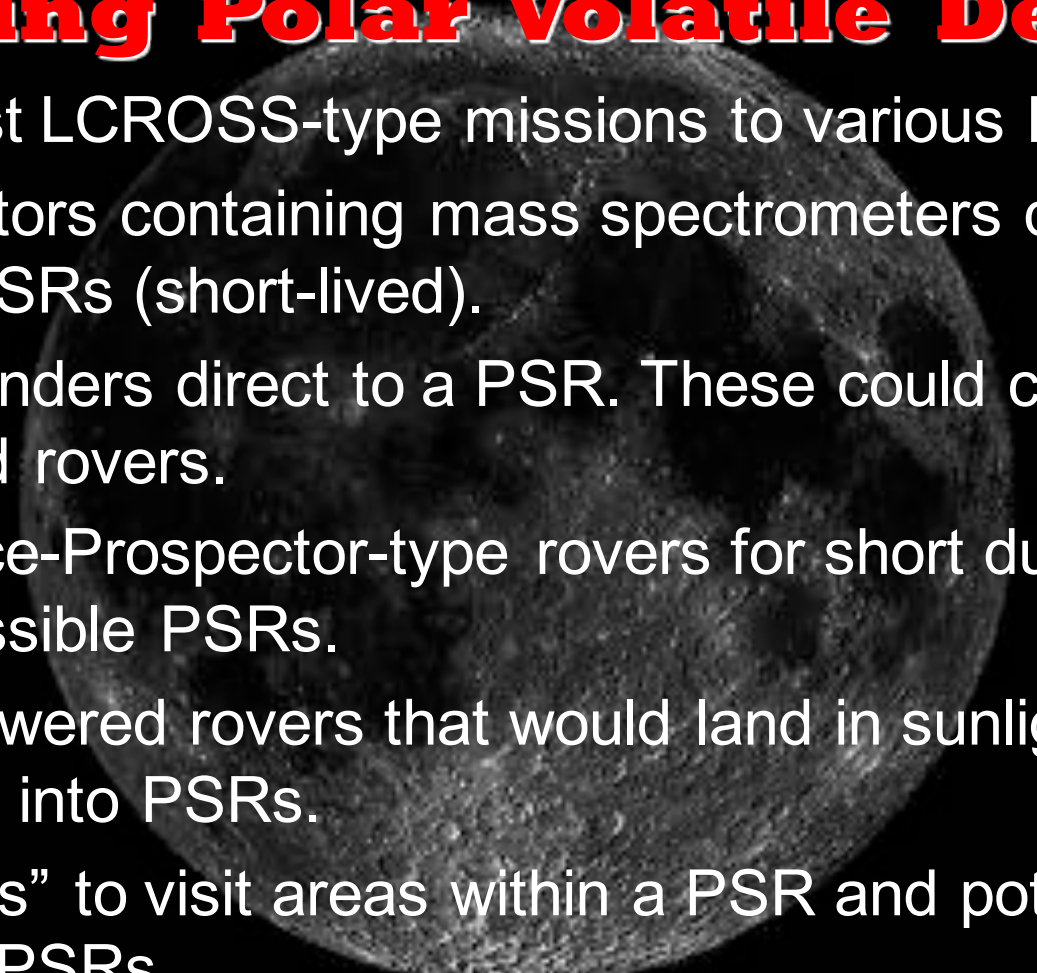



Why Should We Explore Polar Volatile Deposits?

Exploration.

- Define the distribution of such deposits within various PSRs; understand the form the volatiles are in;
- Explore the regolith geotechnical properties of regolith at extremely low temperatures;
- Understand how easy/difficult the volatiles are to extract from the regolith;
- Quantify the refining process for and transport and storage of potential life support consumables and rocket fuels.

Exploring Polar Volatile Deposits

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1. Low cost LCROSS-type missions to various PSRs.
 2. Penetrators containing mass spectrometers deployed to larger PSRs (short-lived).
 3. Static landers direct to a PSR. These could contain RTG-powered rovers.
 4. Resource-Pro prospector-type rovers for short duration visits to accessible PSRs.
 5. RTG-powered rovers that would land in sunlight and traverse into PSRs.
 6. “Hoppers” to visit areas within a PSR and potentially visit several PSRs.

Initial Data

- Elemental abundances and isotopic composition.
- Variability both at the surface and in the subsurface.
- Regolith geotechnical properties.
- Physical form (ice layer, ice-regolith mixture, etc.).
- Environmental data.

Instruments

IR-Vis-UV spectrometer(s).
Oven.
Mass spectrometer(s).
Drill (+/- coring capability).
Penetrometer.
high-resolution camera(s).
Other may be required depending on the mission goals.

Strategy for Exploring PVDs

Initially undertake in situ science at the different PSRs at both the South and North poles:

- Mission options 1 (“LCROSS”) & 2 (Penetrators) could be deployed to the large neutron suppression areas deep with in PSRs. (e.g., **Cabeus, Haworth, Shackleton, Nobile, West of Peary**).
- Mission options 3 (static landers) and 4 (solar rovers) could be deployed to craters that are in partial shadow (e.g., **Peary, western Hermite, western Rhozhdestvenskiy W**).
- Mission options 5 (RTG rovers) & 6 (hoppers) are suggested for detailed PSR investigations if mission opportunities are limited and/or if rovers cannot enter the region.

Technology Development

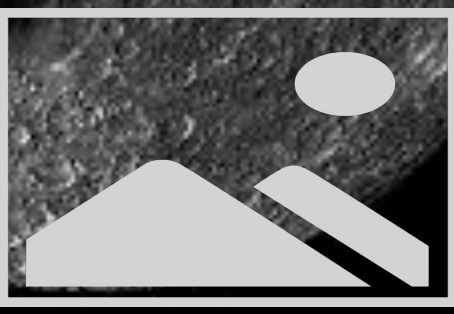
Rover development (building on MSL heritage),

Hoppers will require development.

Operations in extremely low temperatures ($\sim 30\text{K}$).

If sample return is to be accomplished, *significant investment in cryogenic sampling, return, and curation technologies is needed.*

ISRU extraction, refining, transport and storage.



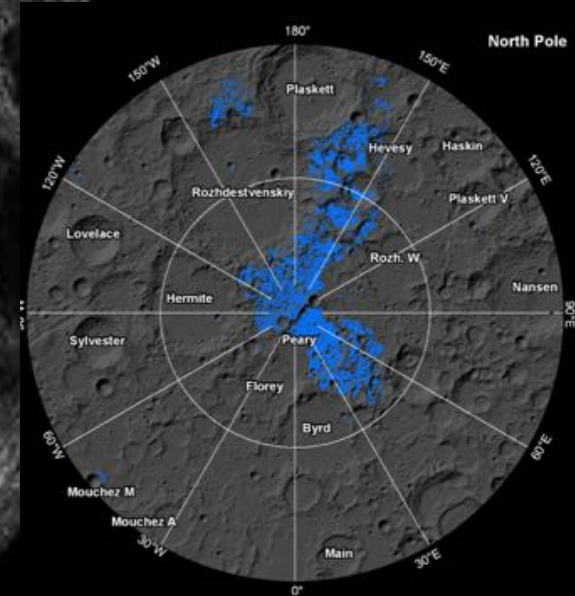
LEAG Volatiles Specific Action Team (V-SAT) Report

North Pole

- Hydrogen >150 ppm
- Average T < 110K
 - Preserves subsurface ice for geologic time
- Slope < 10 degrees
 - Navigable by current rovers
- Outside and adjacent to PSR
 - Lighting available

Peary vicinity meets general criteria and has Earth visibility.

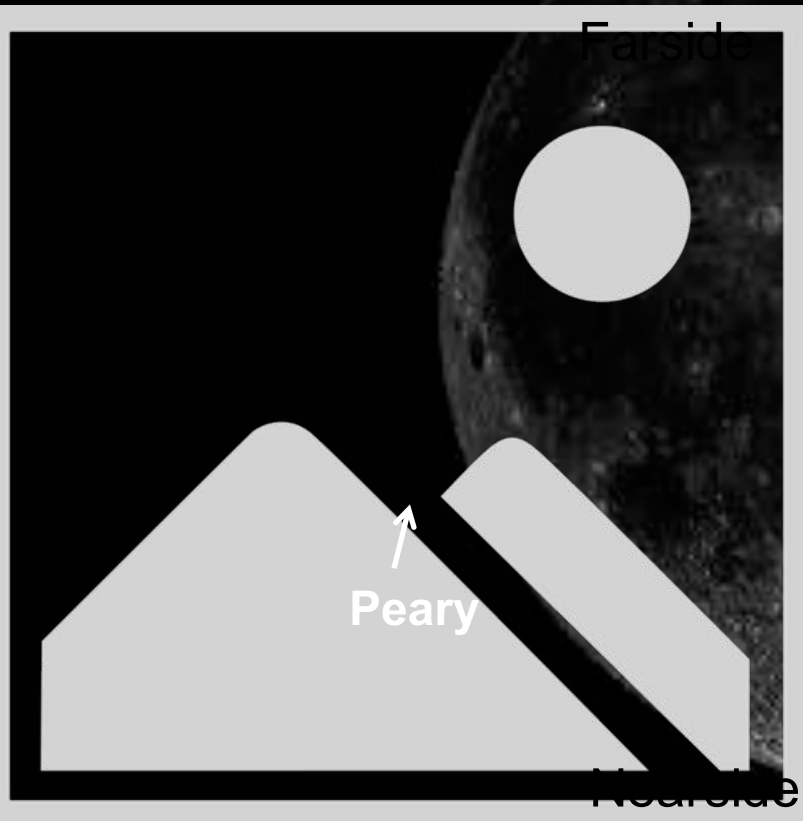
Substantial area of farside also meet general criteria.



http://www.lpi.usra.edu/leag/reports/vsat_report_123114x.pdf

Exploring Polar Volatiles – First Step

Peary Crater PSR – North Pole



Exploration of Lunar Polar Volatile Deposits

- Exploration and science synergies.
- Private sector interest in these resources that have science benefits.
- International interest in the polar volatiles – 6 landed missions to the south pole between now and 2025.
- Initial in situ investigations that leads to cryogenic sample return.
- Technology development in cryogenic sampling, transport, and curation.
- Feed forward to other destinations (Mars, Comets, Ocean Worlds).